3D FEM MODELS OF LINEAR ELECTRICAL MACHINES USED IN FAULT DETECTION STUDIES

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ABSTRACT

An essential part of the intelligent management of an industrial plant is the predictive maintenance to be applied for all the equipment, including also electrical machines. Several fault detection techniques were developed in the past years for the most frequently used rotational electrical machines, but only a few papers were published in the field of condition monitoring of special electrical machines between them of linear machines. In this paper an accurate 3D finite elements method (FEM) based model of a novel modular variable reluctance motor will be presented, which could be very suitable in working out fault detection techniques.

INTRODUCTION

Motor diagnostic techniques as a part of the predictive maintenance technologies have become even more prevalent through the 1990's and into the new century. Hundreds of papers were published in this dynamic research field of electrical engineering [1]. The main part of these papers dealt with the fault detection and condition monitoring of the induction machines, especially of that having squirrel cage rotor. Any of the applied diagnostic methods were based on the more than century old exhaustively theoretical and practical study of the induction machine.

Very few papers could be found in the field of fault detection of different special rotating machines (stepper motors, switched reluctance motors, etc) or of linear machines. Hence any new contribution in this field could be of real interest for all the specialists working in this interesting field.

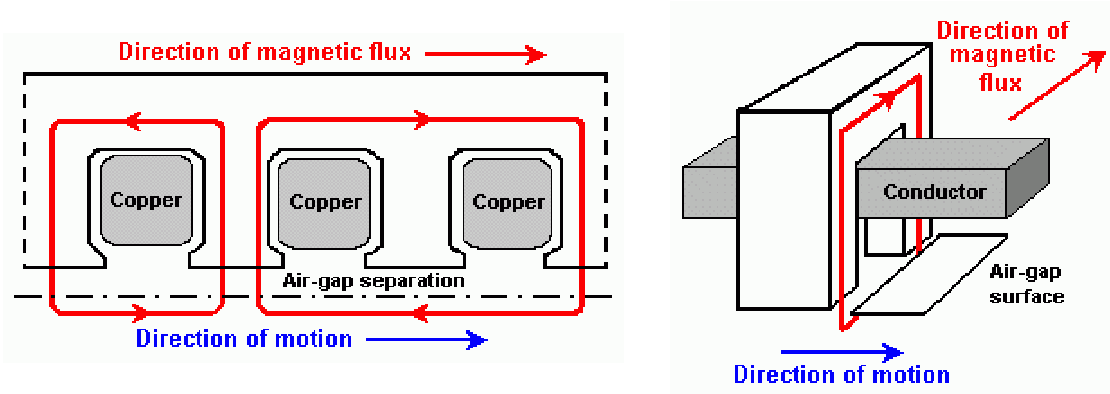
The first step in finding a proper fault detection method for a new type of electrical machine is the deepening of the profound knowledge of its operation in both healthy and faulty condition. Hence a precise model of it is indispensable in this stage of the study.

The paper deals with a precise three-dimensional (3D) finite elements method (FEM) based model of a novel variable reluctance linear machine [2]. The linear machine was designed to be applied especially in advanced linear drives to be used in diverse industrial applications where high precision linear movements are required. The numeric field computations performed using the 3D FEM model will help the designers of the linear machine to better understand the electrical and magnetic phenomenon taken place during the operation of the novel linear machine and to develop useful fault detection methods to be used in the condition monitoring of such types of machines.

THE NOVEL VARIABLE RELUCTANCE LINEAR MOTOR

The market of the high performance linear machines is expected to continuously increase in the coming years [3]. Hence all the researchers working in this field are stimulated to find new and new technical solutions.

The electrical machines have various topologies. In general terms the iron core carries magnetic flux around the windings of the machine in order to create an electromotive force. The magnetic flux can pass in a direction parallel or mainly perpendicular to the direction of motion (see Fig. 1). In the first case, the machine is said to be longitudinal, and in the second case transverse [4].



a) Longitudinal b) Transversal

Fig. 1.

Magnetic flux orientation in electrical machines

The linear machine structure to be presented also has the magnetic flux path transversal to the direction of its movement.

The mover of the linear machine is built up of modules as that given in Fig. 2. The modules are very similar to the modules used in the modular double salient linear motor presented in detail in [5]. The single basic difference is that the poles of this variant are toothed in the transverse direction.

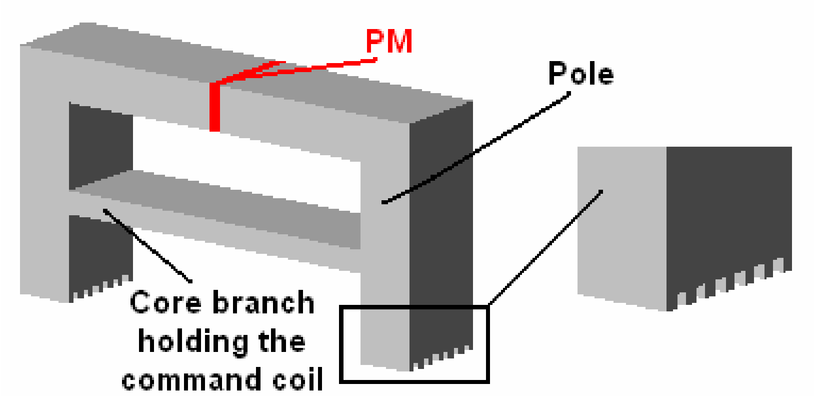


Fig. 2.

The iron core of a mover module

A three-phased variant of the proposed linear motor structure is given in Fig. 3.

The three-phase variant was considered to be the best because of the easy implementation of the control strategy on general-purpose three-phase power converters.

The working principle of the machine is explained in Fig. 4. When the module is passive (its command coil is not energized) the flux generated by the permanent magnet closes mostly inside the mover's iron core.

When the command coil is energized, the magnetic flux produced by the winding practically enforces the flux of the permanent magnet through the air-gap, generating this way tangential and normal forces.

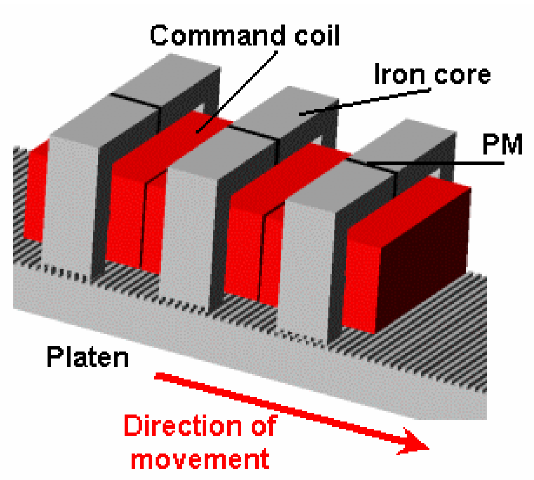


Fig. 3.
The proposed modular linear machine

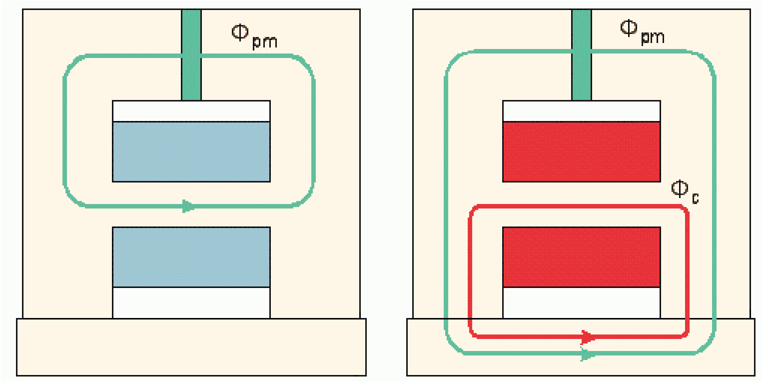


Fig. 4.
The working principle of the modular linear machine

The proposed linear machine structure is in fact a variable reluctance machine. Its movement is possible only if the modules are shifted by a third of the teeth pitch. Energizing the command coil of one module its teeth will be aligned with the teeth of the platen. By sequential feeding the command coils a continuous linear movement of any direction can be assured [6].

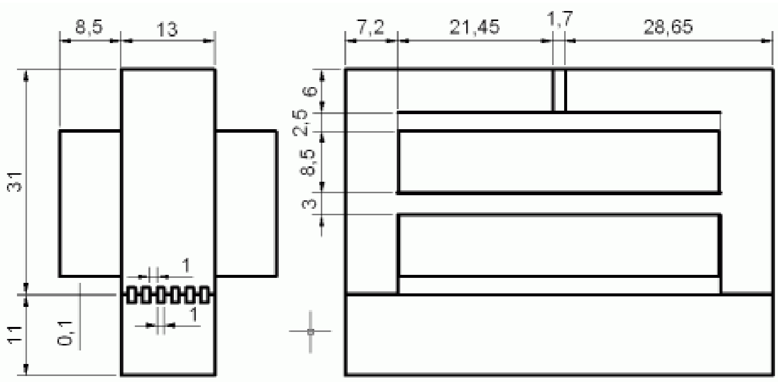


Fig. 5.
Main sizes of the modules

The main dimensions of the sample motor's modules to be further modeled are given in Fig. 5. The figure shows both the lateral and frontal view of the modules.

THE 3D FEM MODEL OF THE MODULAR LINEAR MOTOR

The designed structure of the proposed modular linear machine was analyzed by means of three-dimensional (3D) finite elements method based numerical magnetic field computation [7].

In order to be able to use the developed model also in developing new fault detection methods the entire three-phased motor structure (given in Fig. 6) was analyzed.

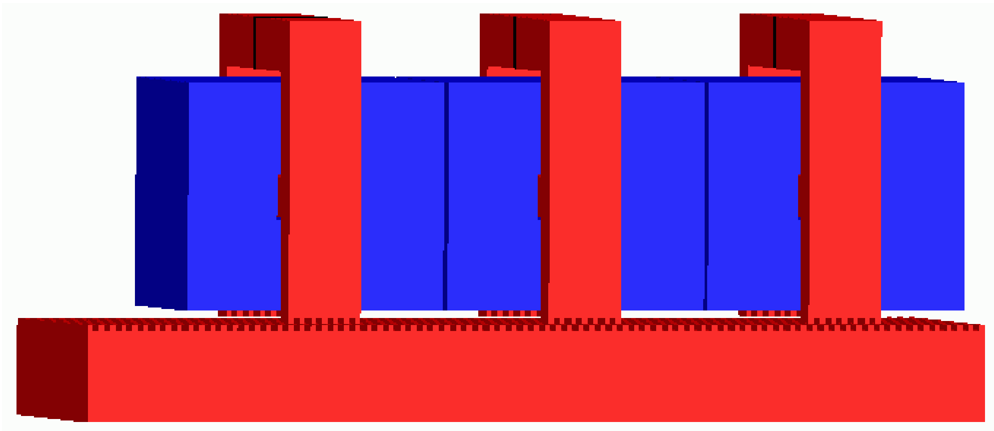


Fig. 6.
The modeled motor structure

A three-dimensional mesh (given in Fig. 7) was generated over the analyzed structure [8]. For better seeing the mesh the zone under one pole was zoomed out.

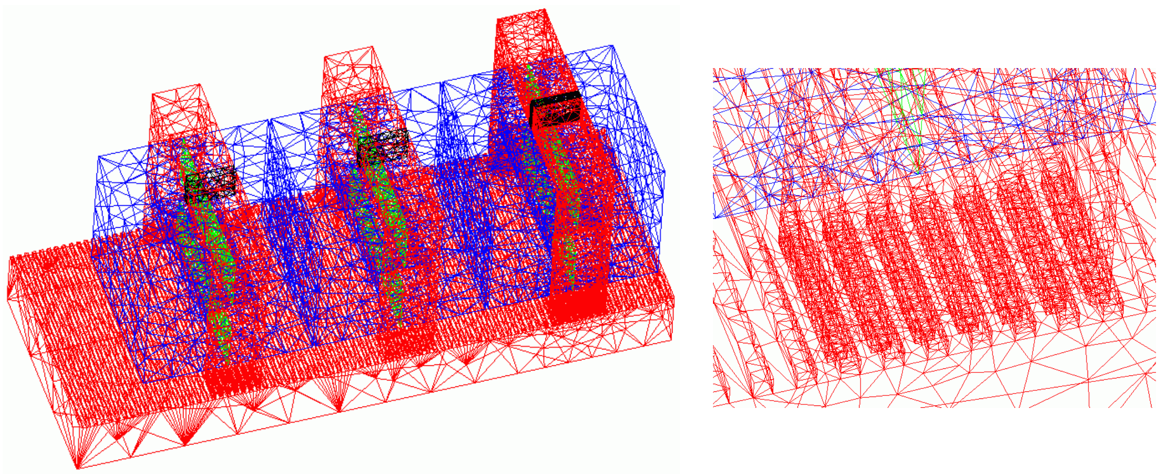


Fig. 7.
The generated 3D mesh

Several working regimes were simulated using the built-up model of the modular linear motor. Here only a single set of results will be presented.

The computations were performed in this case for the situation when the teeth of the left-sided pole are aligned with the teeth of the stator. The command coil of the right-handed module is energized in order to obtain a displacement to the right.

Next results of the 3D field computation performed for the presented motor structure are given. First see in Fig. 8 the field density distribution through the three-phase modular linear structure. In the figure the command coils are shown only in wireframe mode.

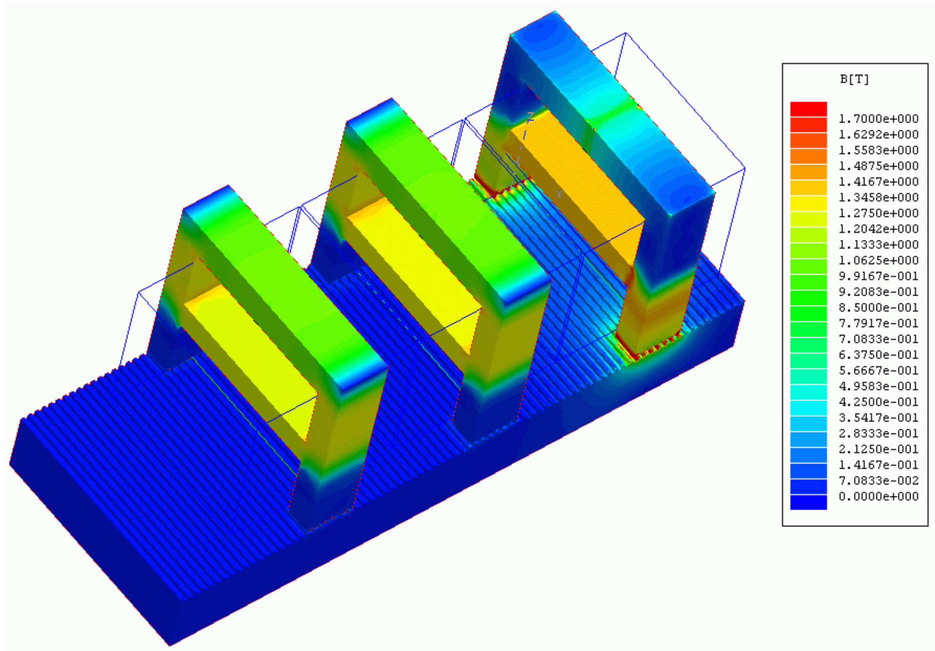


Fig. 8.
The flux density distribution obtained via 3D FEM analysis

As it can be seen from the figure, the working principle of the modular linear motor is proven: insignificant magnetic flux is passing through the poles of the modules which have un-energized command coils. The greatest flux densities can be observed under the activated module (the right-handed one).

It should be of real interest the flux density variation in the air-gap of the linear motor given in Fig. 9. The highest flux densities of course are under the active module. Clearly can be distinguished the 7 peaks due to the 7 teeth of the mover module. Under the two un-energized poles the flux densities are quite small.

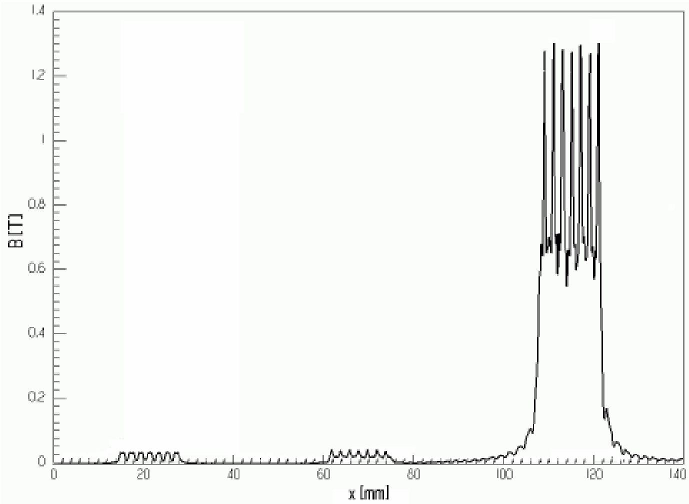


Fig. 9.
The magnetic flux density variation in the air-gap

The total tangential and normal forces computed in this case are the followings: $F_t = 15.07$ N and $F_n = 92.71$ N. As it can be observed the normal attractive forces between the two armatures are very great, over 6 times greater than the useful tangential tracking force developed by the motor.

All the results emphasize the correct design of the presented linear motor.

CONCLUSIONS

The designed modular linear motor in spite of its transverse magnetic flux machine characteristics is relatively simple and can be built up of low cost materials (the mover of classical steel sheets and the platen of massive iron), avoiding the use of expensive SMC [9]. Its modular structure enables to easy adjust the motor performances to the user's requirements without substantial changes in its basic structure. It can be simply controlled by unipolar current pulses.

The built-up 3D FEM model can be used also in developing advanced fault detection methods for this class of electrical machines.

ACKNOWLEDGEMENTS

The work was performed in the framework of the **Joint Hungarian-Romanian Intergovernmental S & T Cooperation Program for 2006-2007** entitled "**Condition monitoring of linear and rotational electrical machine drives by means of advanced data processing instruments**". The authors should like to sincerely thank this way for the financial support.

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